MEASUREMENT OF THE HUMAN FACE USING CLOSE-RANGE DIGITAL PHOTOGRAMMETRY TECHNIQUE

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Abstract

In Malaysia, the data for craniofacial surgery is commonly obtained by using contact physical measurement of the facial features using calipers. This conventional contact method is not practical and time-consuming. Alternatively, a non-contact method such as close-range digital photogrammetry offers a new approach for such measurement. This research focuses on the measurement of the human face (soft tissue) using digital stereo-workstation known as Digital Video Plotter (DVP) to observe the stereo-images in 3D mode and acquire specific 3D spatial data of the face. To provide stereo-images of the face, the system configuration comprises of three pairs of digital cameras (Canon Ixus S500) and the object space control (control frame, camera platform and special chair). For analysis, the comparison is based on the measurement results (craniofacial landmark) between DVP and Calipers. The measurements using DVP are very stable and consistent as compared to the caliper. The 3D spatial data will then be used for further quantitative analysis for facial surgery and for the development of craniofacial database.

1.0 INTRODUCTION

In recent years, modeling and measurement of the human face has gained importance both for medical, computer animation purposes and other applications. For the animation case, a qualitative measurement is sufficient while for the medical case high accuracy is required (D'Apuzzo, 2001). Two different approaches for modeling the human face can be distinguished. One aims high precision and the other aims a good modeling of the facial features without the requirement of high precision. The later is mostly devoted to computer animation purposes (Fua and Miccio, 1997). For animation, virtual reality and teleconferencing purposes, the photorealistic aspect is essential. In contrast, high accuracy is required for medical applications. Two major groups can also be distinguished based on their data source: the first using range digitizers and the second using only images (D'Apuzzo, 2002).

The former approach is usually used for medical purposes such as measurement for planning a surgical intervention (Thomas, *et.al.*, 1996) or for measurement of changes after surgical intervention (Gabel and Kakoschke, 1996). An interesting and attractive use is the forecast of the result of a facial surgical intervention.

A different approach to face modeling uses images as source of data. Various image-based techniques have been developed. They can be distinguished by the types of image data: a single photograph, two orthogonal photographs, a set of images, multi-images acquired simultaneously. Parametric face modeling techniques start from a single photograph to generate a complete 3-D model of the face (Blanz and Vetter, 1999). Exploiting the statistics of a large data set of 3-D face scans, the face model is built by applying pattern classification methods. The results are impressively realistic, however the accuracy of the reconstructed shape is low.

Several methods are currently employed to produce 3-D computer models of the human face. The most commonly used methods include laser scanning, coded light based triangulation approaches and digital photogrammetry. Laser scanning is extensively used for animation purposes. Several laser scanning products are commercially available and some of them have been specifically developed for the modeling of human faces, e.g. Cyberware. These scanners are expensive and the data usually contain noise, requiring editing by hand and sometimes manual registration (Cyberware, 2002).

The coded light based triangulation system (Wolf, 1996) is usually composed of a camera and a programmable projector. These can be used for face reconstruction with relatively inexpensive equipment compared to laser scanners. The system is simple to use and is practical to install (only one camera and a projector). For these reasons it has gained importance in the industrial sector. The method is optimal for static objects. For complex objects such as the human face, multiple acquisitions from different directions and different projection directions are required.

Another methods (Lee and Magnenat, 2000) work in combination with range data acquired by laser scanners. Another image-based method consists of automatically extracting the contour of the head from a set of images acquired around the person (Zheng, 1994). The obtained data are combined to form a volumetric model of the head. The set of images can be generated moving a single camera around the head or having the camera fixed and the face turning. The systems are fast and completely automatic, however the accuracy of the method is low.

The digital photogrammetry method (Maas, 1992) employs more cameras to acquire stereo images of an object. Matching algorithms can be developed to automatically establish correspondences in the images. The result usually consists of a set of corresponding points. Through an accurate calibration of the interior and exterior parameters of the cameras, the 3-D coordinates of the matched points can be computed with high accuracy. The objects to be measured often show insufficient surface texture, which is necessary for the determination of correspondences. In such cases, an artificial texture is projected onto the surface. It can be for instance a dot pattern, a grid pattern or a random pattern. Since all the information needed to model a surface can be acquired in only one step, digital photogrammetry can be described as a simultaneous method to measure surfaces with high accuracy (D'Apuzzo, 1998).

In Malaysia, the data for cranio-facial surgery (human face) is commonly obtained by contact physical measurement of the facial features using different form of calipers (Figure 1). The conventional contact method is not practical and time-consuming. Alternatively, a non-contact method such as close-range digital photogrammetry offers new approach for such measurement. This study focuses on the design and calibration of a prototype stereo-image acquisition system for imaging and recording of human faces via digital photogrammetry.

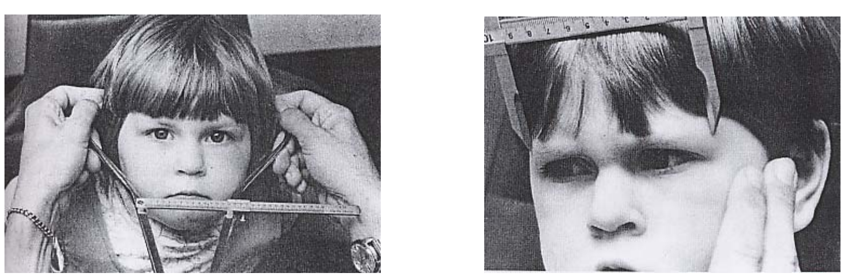

Figure 1: Contact physical measurement of the facial features using calipers

1.1 Objective

The main objective of the study is to evaluate the suitability of the off-the-shelf digital portable stereo-digitizing system (known as DVP or Digital Video Plotter) for craniofacial image acquisition. The following aspects are examined: human face measurement (comparison between DVP and calipers), statistical tests to evaluate the significance of error sizes, and error detection capability of the system. Figure 2 shows the research methodology.

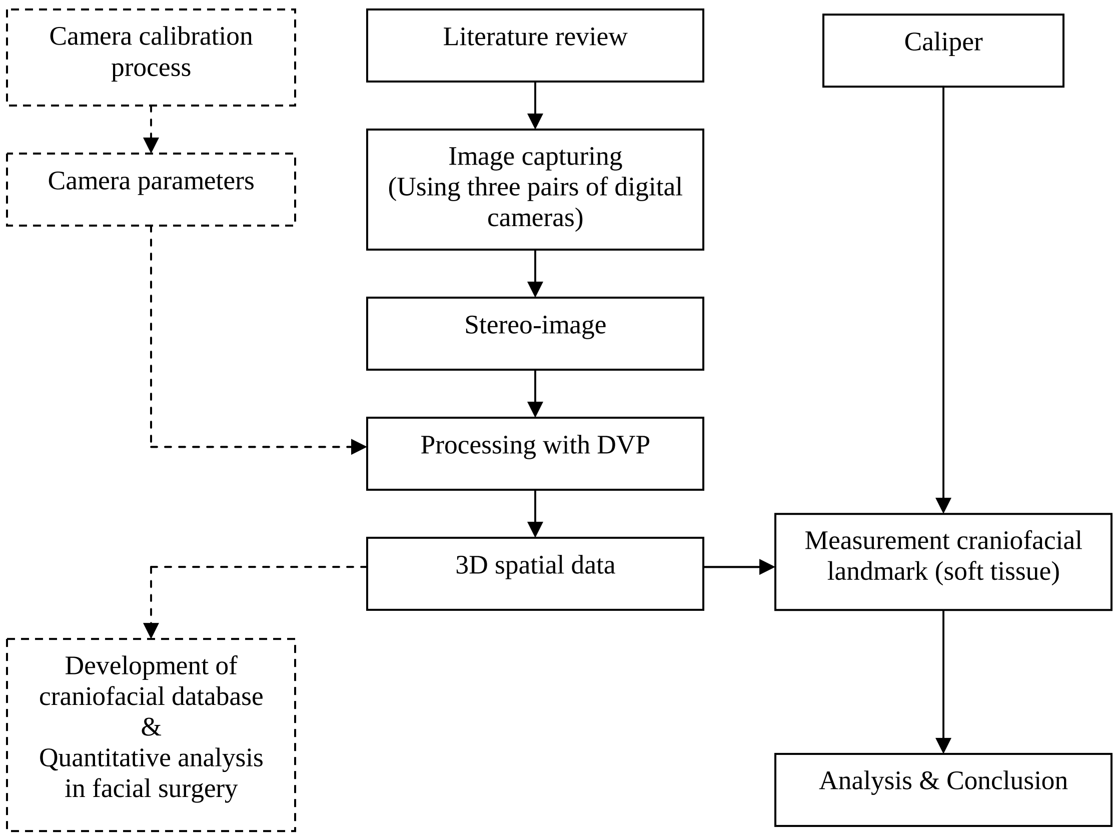

Figure 2: The flowchart of research methodology

2.0 METHOD

2.1 Camera Calibration

All cameras are calibrated using a 3D calibration frame with the scale bar and Exterior Orientation (EO) device. The results of the calibration comprise of camera calibration data such as focal length, principal points offset and lens distortion parameters for the image acquisition system. The calibration process was carried out using a software known as Australis which utilize self-calibration bundle adjustment approach. Figure 3 shows the calibration process: (i) Data processing using Australis; (ii) Data acquisition using two different digital cameras. Table 1 shows the camera calibration parameters for the six digital cameras.

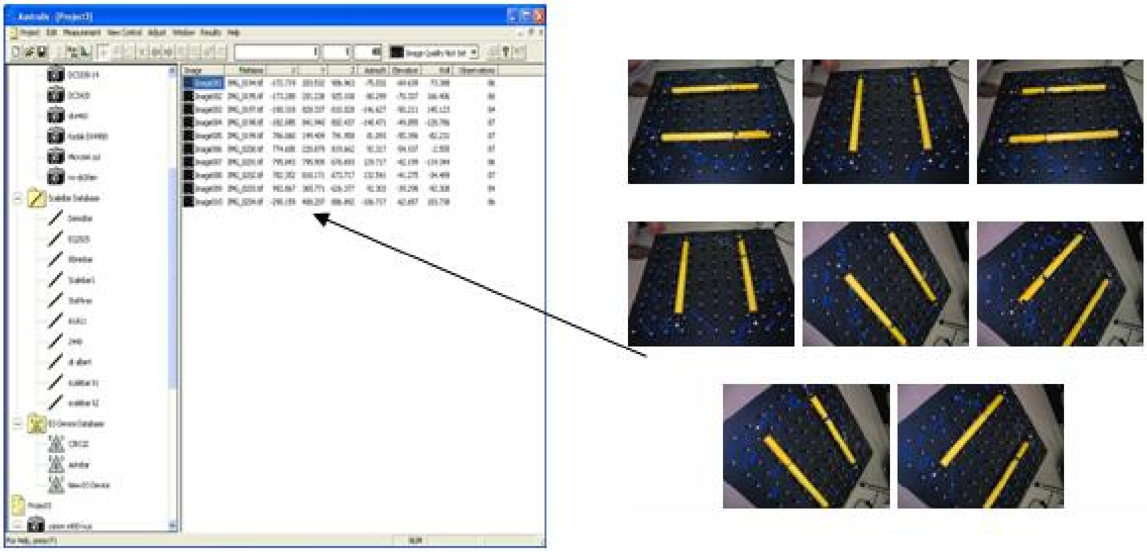

Figure 3: The calibration process

Table 1: Camera calibration parameters

	f	*xp*	*yp*	*k1*	*k2*	*k3*
Camera 1	7.1328	-0.0470	0.0376	2.90138e-003	-7.02488e-005	1.30772e-006
Camera 2	7.1177	-0.0046	-0.0533	2.66960e-003	-4.80232e-005	7.62313e-007
Camera 3	7.0945	-0.0687	-0.0775	2.88220e-003	-6.37212e-005	1.03467e-006
Camera 4	7.1015	0.0517	0.0257	2.54217e-003	-1.56184e-005	-8.55243e-007
Camera 5	7.1880	0.0287	0.0874	2.73114e-003	-5.43708e-005	5.75314e-007
Camera 6	7.1117	0.0363	-0.0502	2.81861e-003	-6.65114e-005	1.56262e-006

2.2 Image Acquisition

Figure 4 shows the setup of the image acquisition system. It consists of a set of six digital cameras (three pairs) and object space control (control frame, camera platform and special chair). During photography, the patients seat on a chair. Figure 5 shows the configuration of the image acquisition system.



Camera Platform **Special Chair** **Control Frame**


The complete set of the image acquisition system **A patient seat on a chair**

Figure 4: The view of an advanced craniofacial data acquisition system using stereo-photogrammetric technique

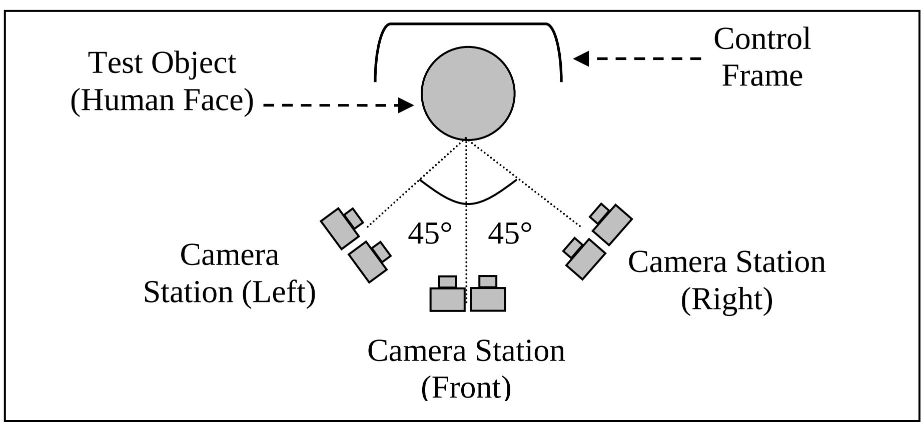

Figure 5: Configuration of image acquisition system

Figure 6 shows a set of two digital cameras (Canon Powershot Ixus S400 with 4.0 megapixels) used in the image acquisition system for capturing the stereo-image. This stereo-image was acquired approximately about 0.7 meters from cameras to the object (face) and the base for the two digital cameras is 0.22 meter

Figure 6 : Two digital cameras (Canon PowerShot S400) in stereo configuration

Before the stereo-image (human face) is acquired, retro-reflective targets were sticked onto the control frame. These targets were used as control points and their coordinates were determined using Australis.

2.3 Test Object

In this study, the objects were human faces. The images were synchronized and used to acquire the stereo-images of the human face (Figure 7 & 8).

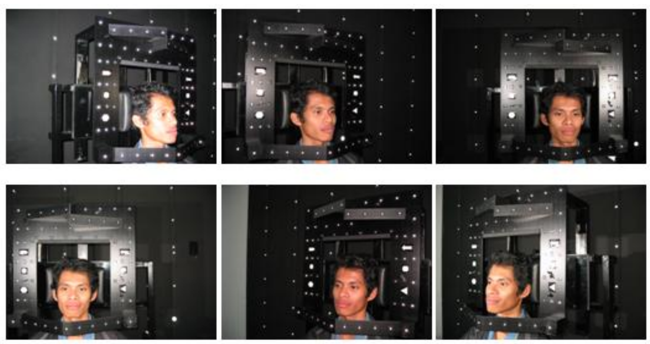

Figure 7: Subject 01

Figure 8: Subject 02

3.0 IMAGE PROCESSING

The whole images were processed using DVP (Figure 9). This system utilizes a computer with two monitors for data processing and stereoscopic glasses for viewing the stereo image in 3D.

Figure 9: DVP system and stereoscopic glasses (NuVision 60 GX)

3.1 Stereo Orientations

Photogrammetric plotting requires a stereomodel to be formed using a pair of images. In a conventional photogrammetric solution using an analogue stereo plotter, the reconstruction could be carried out using optical and mechanical methods. The steps in forming the stereo model include interior orientation, relative orientation and absolute orientation. The DVP system follows the same steps in order to form the stereo model.

3.1.1 Interior orientation

The first step is to perform the interior orientation for the two photographs. This step consists of establishing the parameters for transforming of the image coordinates into photographic coordinates. The fiducial marks that appeared on every photograph were digitized. Fiducial marks are usually located at the corners (Wild cameras) or on the sides (Zeiss cameras) of the photograph. However, in this study no fiducial marks exist since the digital image is not from a metric camera. For digital image, each corner is assumed as a fiducial mark. In interior orientation, the camera calibration parameters such as focal length, principal points offset and lens distortion parameters were used for processing. Figure 10 shows the interior orientation process.

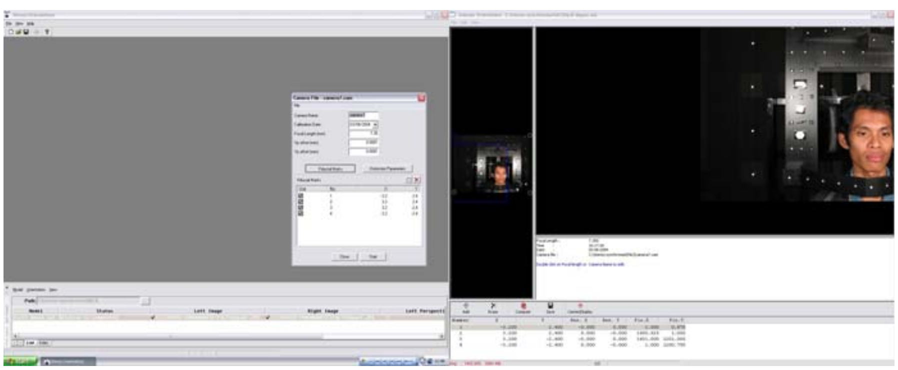

Figure 10: Interior orientation process

3.1.2 Relative orientation

Given two images of a scene taken from different viewpoints, we can create a stereo-model that can be viewed to obtain a three-dimensional impression of the scene. To form a stereo model, the projected image rays through conjugate points must intersect in space, thereby reestablishing the original epipolar geometry of the pair of images (Mikhail *et al.*, 2001). This procedure is known as relative orientation. Using the DVP software, the relative orientation computation is made from observations carried out on strategic points in the model (Figure 11).

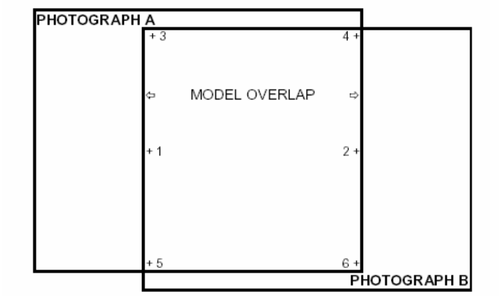

Figure 11: Overlapping photographs based on "Van Gruber Points"

The following illustration (Figure 12) shows the normal distribution of these points when the relative orientation is performed with 6 points. In fact, the solution requires a minimum of 5 points. More than 6 points could be observed in order to improve the solution and to obtain better estimate of accuracy. In this study, fourteen points are observed. Figure 13 shows the relative orientation process.

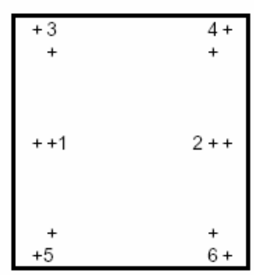

Figure 12: Normal distribution for "Van Gruber Points"

Figure 13: Relative orientation process

3.1.3 Absolute orientation

Once the interior and relative orientations are completed, a stereo model is formed and free from parallax. However, the stereo model is a non-oriented reduction of the object space. In order to take measurements corresponding to the real values of surface model, the scale of the model has to be known. The scale of the model refers to the object space control (control frame). Figure 14 shows the absolute orientation process.

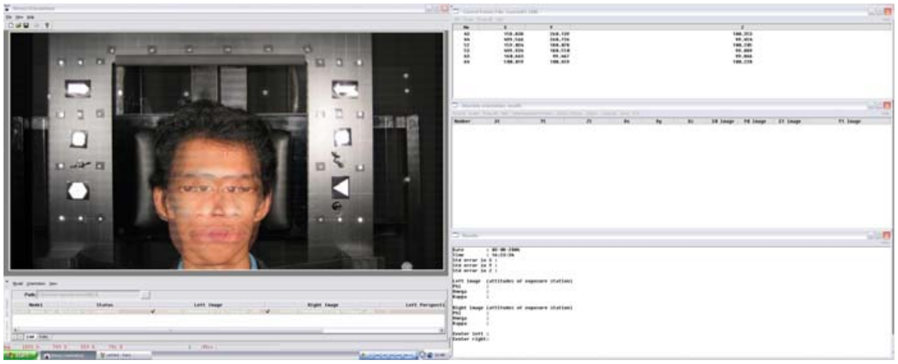

Figure 14: Absolute orientation process

3.2 Vectorization

After the formation of the stereo model to its correct form, measurement can be acquired. Several graphic elements can be created and stored such as lines, polylines, polygons, circles, symbols or vectors. The vectorized elements coordinates are saved in object units. Figure 15 shows the vectorization process.

Figure 15: Vectorization process of a stereo model of the human face

4.0 RESULTS AND ANALYSIS

At present, the results obtained are based on the craniofacial landmarks (Figure 16) measurement using DVP. Table 2 shows the measurement results for subject 01 and subject 02.

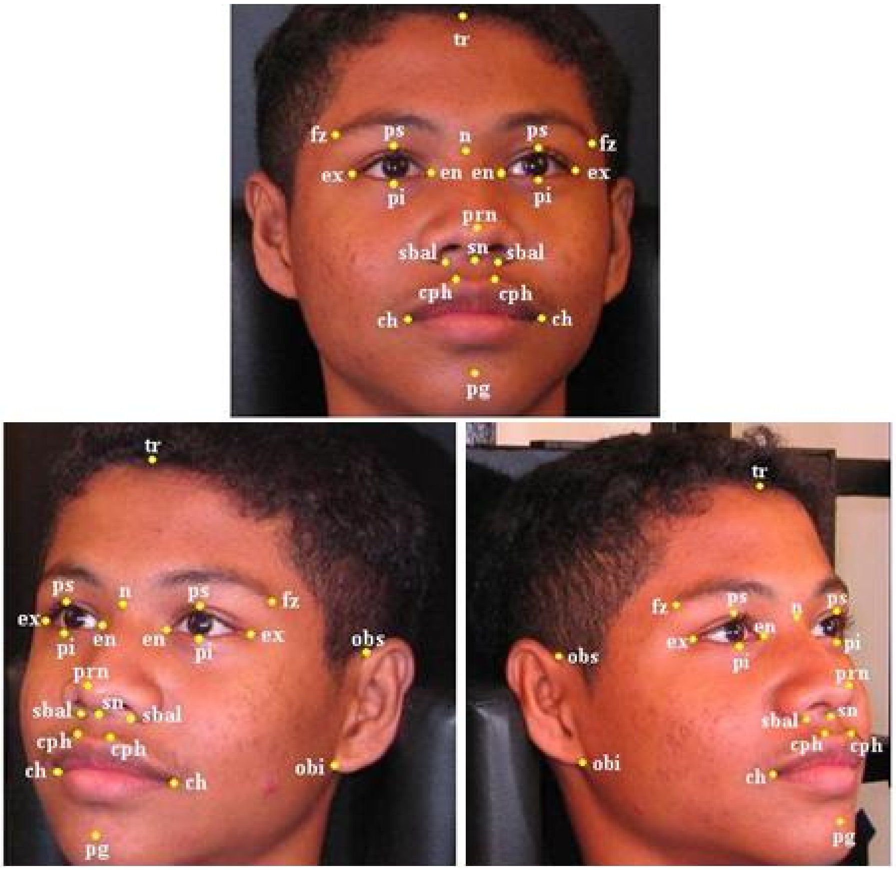

Figure 16: Location of craniofacial landmarks (25 points)

Table 2: Measurement results using DVP

Craniofacial Landmarks	Subject 01 (mm)	Subject 02 (mm)
ex-ex	88.687	109.839
en-en	31.981	28.045
ch-ch	53.468	51.487
sbal-sbal	27.981	23.546
fz-fz	110.864	122.38
ex-en (L)	35.105	38.216
ex-en (R)	35.524	38.046
tr-n	66.782	73.520
n-sn	46.476	54.008
sn-pg	40.756	51.994
n-prn	38.007	42.731
prn-sn	25.837	20.056
ps-ps	63.746	60.348
pi-pi	63.451	60.782
cph-cph	14.187	15.521

For analysis, the comparison is based on the distance (straight measurement) between DVP and Calipers (figure 17).

Figure 17: Measurement using caliper

Table 3 and Table 4 show all the measurement for subject 01 and 02, based on standard craniofacial landmarks (Kolar and Salter, 1997) on the human faces. Figure 18 and Figure 19 show the Std. Dev. Graph of measurement for subject 01 and 02.

Table 3: Craniofacial landmarks measured using caliper and DVP (Subject 01)

No.	Subject 01 Craniofacial Landmark	N	Caliper (mean) mm	Std. Dev.	DVP (mean) mm	Std. Dev.
1	ex-ex	10	89.00	1.69	88.687	1.17
2	en-en	10	32.50	0.72	31.981	0.93
3	ch-ch	10	53.90	0.15	53.468	0.79
4	sbal-sbal	10	28.35	1.51	27.981	0.57
5	fz-fz	10	111.15	1.34	110.864	0.44
6	ex-en (L)	10	35.50	0.39	35.105	0.71
7	ex-en (R)	10	36.10	0.51	35.524	0.68
8	tr-n	10	65.00	2.56	66.782	2.45
9	n-sn	10	47.50	3.17	46.476	2.99
10	sn-pg	10	41.50	2.72	40.756	2.01
11	n-prn	10	38.55	2.44	38.007	2.56
12	prn-sn	10	25.30	0.76	25.837	0.84
13	ps-ps	10	62.65	0.68	63.746	0.66
14	pi-pi	10	62.60	1.16	63.451	0.81
15	cph-cph	10	14.65	0.34	14.187	0.62

Table 4: Craniofacial landmarks measured using caliper and DVP (Subject 02)

No.	Subject 02 Craniofacial Landmark	N	Caliper (mean) mm	Std. Dev.	DVP (mean) mm	Std. Dev.
1	ex-ex	10	110.40	0.78	109.839	0.94
2	en-en	10	27.30	0.69	28.045	0.78
3	ch-ch	10	52.30	0.45	51.487	1.01
4	sbal-sbal	10	23.35	0.21	23.546	0.61
5	fz-fz	10	120.30	1.91	122.38	0.48
6	ex-en (L)	10	39.60	0.83	38.216	0.84
7	ex-en (R)	10	38.85	1.45	38.046	0.76
8	tr-n	10	75.05	3.12	73.520	3.01
9	n-sn	10	54.75	2.67	54.008	2.78
10	sn-pg	10	51.00	2.15	51.994	2.13
11	n-prn	10	43.25	2.89	42.731	2.21
12	prn-sn	10	20.60	0.38	20.056	0.83
13	ps-ps	10	60.65	1.46	60.348	0.67
14	pi-pi	10	62.25	1.87	60.782	0.96
15	cph-cph	10	15.70	0.44	15.521	0.55

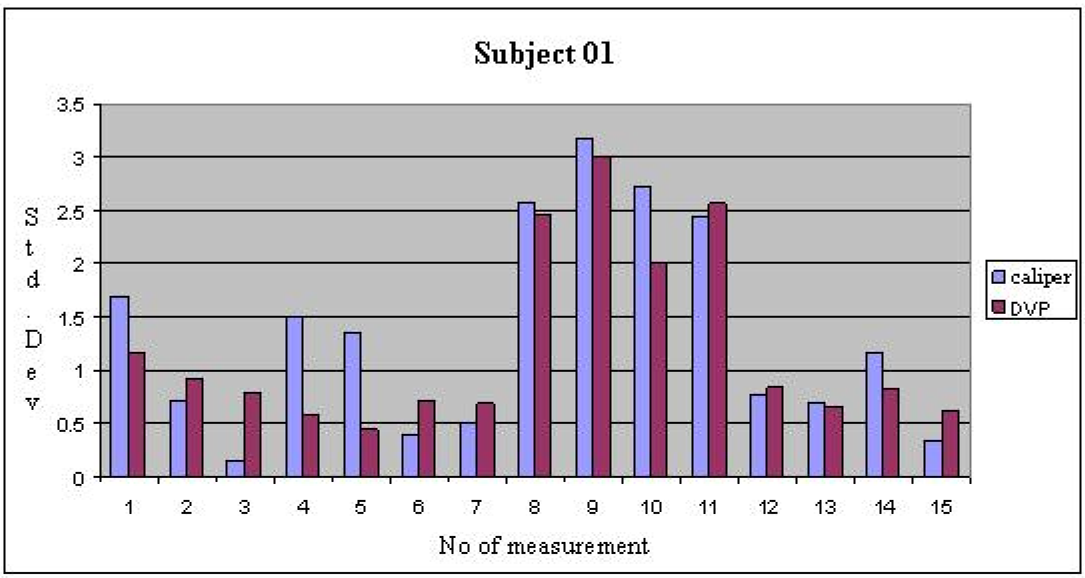

Figure 18 : Std. dev. graph of measurement (Subject 01)

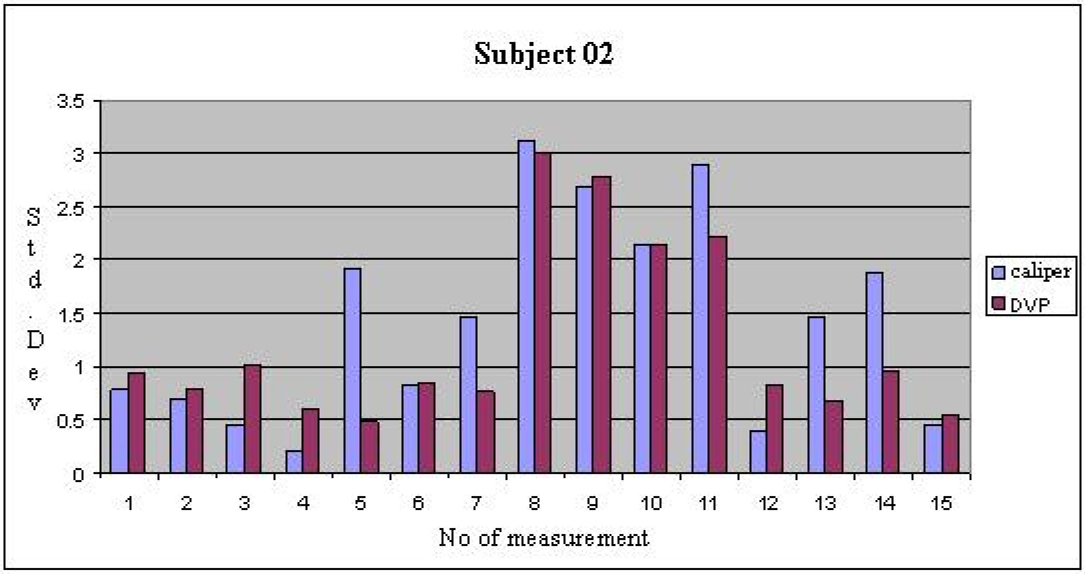

Figure 19: Std. dev. graph of measurement (Subject 02)

Based on Table 3, Table 4, Figure 18 and Figure 19, the results of measurement using DVP are stable and better than the caliper, because measurement using DVP can be done easily and accurately on the digital stereo-images, and no contact physical (direct) measurement. However, the method of measurement via caliper is based on contact physical measurement of human faces, and the results depend on the skill of the observer.

Unfortunately some analysis (std. dev) from DVP produces big differences (std. dev; 2.01~3.01) when compared with calipers. These differences are expected because it is difficult to digitize some points correctly at its true location (e.g. tr, n, prn, sn and pg) (Figure 20).

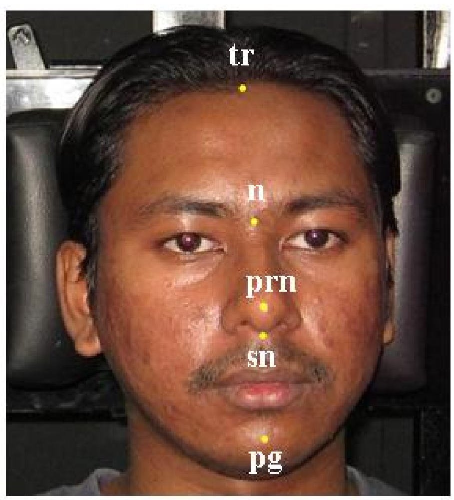

Figure 20 : Location of tr, n, prn, sn and pg

5.0 CONCLUSION

From this study, it was found that stereo-imaging system which includes the object space control can be used and employed for imaging and recording of human faces, especially for human face measurement. The measurements using DVP (with photogrammetry technique) are very stable and the results are consistent compared to caliper. However, the measurement of human face is very difficult because some points are not known exactly and sometimes could not be digitized correctly.

DVP can be used to digitize the stereo-images to produce spatial data of human face such as contour, spot height and others. The spatial data could be used for further quantitative analysis in facial surgery and for the development of craniofacial database.

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